III.

WHAT ELECTRICITY IS: ILLUSTRATED BY SOME NEW EXPERIMENTS.

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Electricity is, to all of us, more or less surrounded with an atmosphere of mystery.

When we speak of Light, or Sound, or Heat, we feel that we are dealing with familiar things, — things so familiar to our every-day life that it seems useless to try to define or describe them. Every day the sunlight fills all space; it dazzles our eyes; it falls upon the objects around us, and makes them visible; and though through the evening, when the sun is gone, we substitute for a while a gas flame, or a candle, or an electric light, we have then through the day had so much of it that at night we are glad to be rid of it, and have darkness for our hours of repose.

So, too, from babyhood to old age, all day long and every day, we are listening to one or another sound, whether the voices of friends, or the busy hum of city life, or the delights of music, or the ticking of the clock at night. Indeed, so constantly are our ears filled with sounds, that, when we go alone on to a high mountain, or a desert plain, where there are no trees to rustle with the wind, the silence is painful and oppressive and awful.

Heat, too, is equally familiar, perhaps even more so: for what is more familiar than the warmth of sunshine? And is not the fireside the very centre, as well as emblem, of our home?

When, however, we speak of that other great force of nature, *Electricity*, we feel that we are departing from familiar ground. It is shrouded in mystery; it is something we cannot see, or hear, or feel, — something we cannot easily describe or define. We speak of it in the same breath with spirits and with ghosts. The reason, I take it, is because the human body has no organ especially adapted to recognize electrical phenomena. While the eye receives the ray of light, the ear the ray of sound, and any part of

the surface of the body feels the heat, the presence of electricity cannot be detected by any of our senses. Electricity cannot be seen, or heard, or felt; it is tasteless and odorless.

Subjectively considered, then, electricity eludes our grasp.

Objectively, however, electricity is as familiar to us as light, or sound, or heat. Its phenomena have been as carefully studied, and its laws are as accurately known.

Let us for a moment recall the physical explanation of light and sound. Let us picture to the eye of the imagination the mechanics of a ray of light.

When we stand out of doors on a cloudless night and look above us, we see a multitude of stars. The telescope tells us that some of these are suns, some are moons, and some are other worlds than ours.

The nearest of them is distant millions of miles, and yet we can see them. There is a chain of something linking the star at which we are gazing to the eye. This chain we call, familiarly, a ray of light. Physicists tell us that along the pathway from the star to our eyes there are chasing each other with enormous speed a multitude of waves of light.

If we turn our eyes to another star, it too sends to our eyes its waves of light. If we go to a distant part of the earth, the same stars send rays of light to us there. And so we find that each of the multitude of stars is radiating ceaselessly in all directions multitudes of waves of light.

Between us and the stars, and between the stars extending everywhere through visible space, is the medium that transmits these waves, crossed and intercrossed continually with countless waves of light,— a medium rarer than the rarest gas,— the medium that is still left in space when we remove from it all solids and liquids and gases, *the ether*.

Objectively considered, then, light is a wave motion of the ether that everywhere surrounds us and fills all space. By a similar wave motion, but in a coarser medium, the air, sound is transmitted from place to place.

By means of his vocal organs, a public speaker moulds the current of air that issues from his lungs into waves of sound. These waves of sound are radiated in all directions, and fall upon the various listeners' ears.

Something analogous takes place when we drop a pebble on to the surface of a placid lake. From this centre of disturbance,

waves of water are radiated in all directions until they reach the shore. Waves are likewise radiated downward to the bottom of the lake, and fishes have organs, like our ears, that enable them to take cognizance of these vibrations.

In the case of waves of water, or waves of sound, or waves of light, we know there is no bodily transference of a particle of water, or air, or ether, from the centre of disturbance to the shore, or ear, or eye. Each particle moves at the most only through a minute fraction of an inch; but each pushes the next, and this the next, so that motion, and not matter, is what is transmitted to a distance. Indeed, this propagation of motion, in contradistinction to propagation of matter, is the essential characteristic of wave motion.

Who has not seen a wave pass over a field of grain? Each particle bows its head but for a few inches, yet the wave passes on to the utmost limit of the field.

Sound, then, is a wave motion transmitted through the air. Light is a wave motion transmitted through the ether. But both of these media are also capable of having set up in them currents in which there is an actual bodily transference of the medium from place to place through considerable distance.

In the case of air, we call this motion the wind. In the case of the ether, I propose to show that it is a current of electricity.

As wind is the bodily forward motion of the medium whose vibratory motion we call sound, so a current of electricity is the bodily forward motion of the medium whose vibratory motion we call light.

A current of electricity is a breeze of light.

We may, perhaps, best get a realistic conception of electric currents, whether flowing through open space, or confined to a specially provided metallic conducting path, by first picturing to ourselves the phenomena of air currents, with which we are more familiar, and then mentally transferring these phenomena from the air to the more subtle medium, the ether. The analogies are very striking, and will materially aid the imagination in picturing electrical phenomena.

In the islands of the Pacific Ocean there is almost always a breeze, either from the land to the water, or from the water to the land. In the daytime the island is heated by the sun, its air is rarefied and rises, and the cooler breeze rushes in from the ocean to take its place. At night the island cools, the air descends, and

an outward breeze is produced. There is always a breeze from an area where the air is condensed, and towards an area where it is rarefied. This local condensation and rarefaction of the air are the cause of breezes and winds and hurricanes. The maps issued by our weather bureau show areas of high and areas of low barometer, and the direction of the wind is always from the one to the other.

If, instead of allowing the wind to blow freely through space, we confine it to a narrow channel,—if, for instance, we produce an air pressure at one end of a long iron pipe, we get through the pipe a strong current of air, —as, for example, in pneumatic tubes, in which the current of air carries along small carriages, in the tin pipes used to convey the hot-air currents from our furnaces to the registers, and in the pipes used for distributing illuminating gas from the central gasometer to the houses about the city where it is burned.

The wind blowing through space is made evident to our eyes by its scattering of a handful of dry leaves, or dust, or bits of paper. It bows and bends the branches of the trees. A candle flame exposed to it is distorted, or instantly blown out. Its direction is more accurately indicated by the familiar weather-vane, and its strength is measured, if we will, by the anemometer.

As with the wind of nature, so too with the electric wind. If we substitute for our Pacific island a metal ball suspended in mid-air by a silken cord, and let the ocean be represented by the surrounding atmosphere on a moist day, and produce upon the ball an area of *electric* condensation, or, as an electrician would say, a positive electric change, we shall have an electric breeze blowing outward in all directions, which will last so long as the electrification of the ball is above that of the surrounding air. This may be made evident to the eye by placing upon the ball a handful of bits of paper, or dry leaves, or dust, any of which will be instantly blown away and dissipated in all directions. If a lighted candle be brought near the ball, its flame will be bent by the breeze, and possibly be blown out.

If instead of allowing this electric wind to blow away in all directions we confine it to a narrow path,—if, for instance, we connect the ball to the earth by a metallic wire, —we get through the wire a strong current of electricity, whose direction may be determined by the electric weather wave, a magnetic needle, and whose strength may be measured, not with the anemometer, but by the galvanometer.

We may conceive of this electric wind as a breeze of the ether: the proof of the identity will be given later.

It is in currents flowing along metallic wires that the phenomena of electricity have been most carefully studied, and it is the phenomena of such currents that have therefore been for the most part utilized in electrical inventions.

Nature's wind is used to waft our ships across the seas, and it is perhaps not a wild idea to conceive of electric repulsion utilized to support and propel heavily laden air ships through the space above our heads; but it is with electric phenomena as they have been investigated and utilized up to the present time that we have to deal in this article, and this, as we have seen, means the phenomena of electric currents flowing through metallic wires.

What are some of these phenomena?

Electricity — or what we shall soon see is the same thing, a current of ether — passes readily through a copper wire. To the ether current, the wire is hollow; in electrical terms, it is a good conductor. It also passes quite readily through an iron wire, but not so readily as through copper. It passes still less readily through a wire of carbon. It passes more readily through a large wire than through a small wire. In all wires, there is more or less ethereal friction or electric resistance.

In virtue of this ethereal friction or electric resistance, the current heats the wire through which it passes, — of course heating a small wire more than a large one, and heating an iron wire more than one of copper, and a carbon wire most of all. We see this in our household system of electric lighting. The current passes from the central station and throughout our houses to the lamps, over comparatively large wires of copper, which it warms only slightly; but coming to the lamps, it passes through a fine wire of carbon, in which the friction and consequent heating is so great that the filament becomes white hot; and were it not contained in a glass globe, from which the air has been removed, it would take fire and disappear.

Again, an electric current flowing in a wire coiled around a bar of iron converts the bar of iron into a magnet, so that it may attract an iron armature placed near its end, and thus do mechanical work. The converse of this is equally true, and if we move an iron armature to or from the end of an iron bar around which a wire is coiled, an electric current will be set up in the same coil, and by means of the connecting wires may be carried to a distance

and utilized. On this latter principle depends the dynamo machine, which furnishes electricity to be used for light or power. On the former depends the electric motor that propels our street cars, and furnishes power to many of our industries.

Again, the electric current flows through wires with enormous velocity, and consequently it offers an excellent vehicle for the rapid communication of intelligence, — for telegraphy. A telegraph wire between two cities is merely a path through which the current may readily flow. At one end is a reservoir of electricity. The "key" is a device by which electricity may be allowed to flow into the line. By allowing small quantities of electricity to flow into the line at intervals of time in accordance with a prearranged code, and noting at their distant end their arrival, we may communicate any ideas that are capable of being expressed in such a code.

The arrival of these little currents of ether may be manifested to the eye in various ways. In the so-called needle telegraph, the current passing by a magnetic needle causes it to point in a given direction, just as the wind passing a weather-vane causes it to point in a given direction.

If it were possible to have on one hill-top a reservoir of air under pressure, or wind, and a key by which small puffs of air could be let out at intervals in accordance with a pre-arranged code, and on a neighboring hill a weather-vane, we might thus have a wind telegraph operated exactly as is the electric telegraph. But such a telegraph would be slow and cumbersome in operation, and is not likely to come into general use.

There is one other phenomenon on which I desire to dwell a moment, — a phenomenon of great importance, as it furnishes the first proof of the identity of electricity and the ether.

Suppose we have an ordinary telegraph wire in which there is a steady current flowing. Suppose ten feet away from this wire, and entirely disconnected from it, we arrange a short wire with any suitable means of detecting an electric current in it, should such a current exist. So long as the current in the first wire flows steadily on, there will be no current in the secondary wire. If, however, the current in the first wire be broken up into rapid pulsations, say 100 per second, by rapidly opening and closing the circuit we shall find in the secondary wire short pulsating currents occurring with the same frequency. How does this action take place? How are the impulses transmitted across apparently

unoccupied space? The only conductor between them is possibly the moist air; but the same phenomenon takes place if the air be dry, or even if it be entirely removed. The only remaining explanation is that the pulsations are carried from one wire to the other by means of the intervening ether which we know fills all space. We shall see in a moment that the pulsations are transmitted by means of a wave motion of the ether from the one wire to the other.

Meanwhile, let us look at the analogy of this phenomenon as it takes place in a current of air.

Suppose we have a pipe in which there is a steady current of air flowing. Suppose ten feet away we place our ear. So long as the current of air flows steadily on, no sound will be heard. If, however, the current in the pipe be broken up into rapid pulsations, say 100 per second, by rapidly opening and closing its end, which may be done by means of a reed such as is used in organs, the pipe will radiate in all directions waves of musical sound of a pitch due to 100 vibrations per second, and this sound will of course be heard by the ear. In this case we have a current of air, by rapid interruptions, converted into waves in the air, or sound.

Analogy indicates that, in the former case, we had a current of ether (or electricity), by rapid interruptions, converted into waves in the ether (or electrical waves). But we must have stronger proof than the indications of analogy, and it is readily forthcoming.

If the interrupted current in the wire radiates ether waves, these ether waves are really nothing more nor less than waves of light. Unfortunately, the eye only detects waves of light that are a small fraction of an inch in length, while the waves radiated from the most rapidly interrupted electric current are many inches in length. Nevertheless, the complete identity of waves radiated from an interrupted electric current and from a source of light has been confirmed by the study and identification of many of their phenomena, first by Maxwell, and later by Hertz; the most striking proof being that waves radiated from an electric wire are propagated through space with a velocity of 300,000,000 meters per second, which is the same as the velocity of light.

So far as wave motions are concerned, therefore, those radiated from an electric wire are just as much ether waves as those radiated from the sun, or any other source of light.

It remains now to show the identity of the electric current and a current of ether. For this I invite your attention to some exper-

iments of my own, that seem to me to go far towards establishing this identity.

If we can find somewhere in nature a breeze of ether blowing with the necessarily enormous velocity freely through space, and show that it exhibits both qualitatively and quantitatively the same properties as an electric current, the simplest possible supposition that we can make is that they are identical.

Now, the earth in its daily journey round the sun rushes through the ether that fills all space with enormous velocity, and to the observer on the surface of the earth this is the same thing as if the earth were at rest and the ether flowed by with this same velocity. Just as the observer on the deck of a swift steamship at sea feels the same breeze, whether the ship moves forward with a speed of twenty miles an hour through a calm atmosphere, or the breeze blows with a velocity of twenty miles an hour by the steamship when at anchor.

Now, our problem is to detect and measure this ether breeze, and show that qualitatively and quantitatively it possesses the properties of a current of electricity. This I have done in the following way.

Before us stands a very sensitive balance, capable of detecting a variation in weight of one part in a million. I have replaced the scale-pans with thin disks of brass, ten centimeters in diameter. Above and below each disk, and supported from the floor of the balance by glass legs, are other similar disks of brass. The two suspended disks are, of course, free to move up and down, but remain at rest so long as the equilibrium of the balance is undisturbed.

The remaining four disks are rigidly fixed, excepting as each can be raised or lowered by a delicate micrometer screw. For convenience I will designate the right-hand disks *Rt*, *Rm*, and *Rb*, indicating respectively right-hand top, right-hand middle, and right-hand bottom. Similarly, I will designate the left-hand disks *Lt*, *Lm*, and *Lb*. By means of a suitable battery I may electrify any of these plates, either positively or negatively.

Suppose, now, I electrify the beam of the balance, and consequently plates *Rm* and *Lm* positively. If the distances between plates are in all cases the same, the index will remain at rest. If it deflects, we know the distances are somewhere unequal, and must be adjusted by means of the micrometer, until there is no deflection.

If, now, I electrify *Rt* negatively, it will attract and lift *Rm*, and the index will move to the right.

If, however, I at the same time electrify *Lb* positively, it will tend to repel and lift *Lm*, and, as the repulsive lifting of *Lm* is equal to the attractive lifting of *Rm*, the index will remain at rest. That is, an *attraction* between *Rt* and *Rm* is balanced by a *repulsion* between *Lb* and *Lm*.

If, now, I suddenly change the electrification of the beam of the balance, and consequently of the plates *Rm* and *Lm*, to negative, we have a *repulsion* between *Rt* and *Rm*, balanced by an *attraction* between *Lb* and *Lm*.

Now, it can be shown by purely mathematical reasoning from electric phenomena, (see Maxwell's Electricity and Magnetism, Chap. XIX.,) that an ether current flowing between two positively electrified plates would, provided it possessed the electro-magnetic properties of a current of electricity, diminish their repulsion. If it flowed with the velocity of light, and had quantitatively, as well as qualitatively, the electro-magnetic properties of a current of electricity, it would just *neutralize* the repulsion.

If, on the other hand, it passed between two plates, one of which was charged positively and the other negatively, it would just double their attraction.

If, instead of moving with the velocity of light, 300,000,000 meters per second, it moved only $\frac{1}{10000}$ as fast, or 30,000 meters per second, the repulsion between similarly electrified plates would be diminished by one part in ten thousand, and the attraction between oppositely electrified plates increased one part in ten thousand.

Now, it can be further shown from purely astronomical measurements that our balance is, on the 22d of December at noon, carried through space with a velocity of 30,000 meters per second.

Observations made at noon on that day, then, ought to show the index of the balance one side of the position of equilibrium when the movable plates are electrified positively, and the other side when electrified negatively. The difference should indicate a total change of force of one part in twenty-five hundred.

This deflection of $\frac{1}{2500}$ is that due simply to the rotation of the earth around the sun. That due to the rotation of the earth about its axis is too small to note. But the whole solar system is moving towards Hercules with a velocity of 8,000 meters per second.

On the 22d of March this velocity would have to be added to the

velocity of the earth in its orbit, and on the 21st of September subtracted. On the 22d of December it would have no effect. Our deflection on March 22d, then, should be about $\frac{1}{2000}$; on December 22d, $\frac{1}{2500}$; and on September 21st, $\frac{1}{2700}$.

Of course, in actually taking observations, it is necessary to use all six of the plates variously grouped and variously electrified, in order to get rid of accidental phenomena.

Even then the accidental phenomena frequently mask that for which we are searching, and it is only from the discussion of a considerable series of observations that results of value are obtained.

I began my observations last September, and have continued them at intervals since. The results observed are of the order of magnitude predicted, and vary, as expected, with the season of the year.

If, continued until next September, the cycle is complete, I shall feel even more sure of having discovered the phenomenon for which I am searching, and of showing that the motion of the ether possesses, both qualitatively and quantitatively, the properties of an electric current, — that *an electric current is a bodily forward motion of that same ether whose undulations we call light.*